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LATEST DEVELOPMENTS IN AMERICAN STEEL DESIGN SPECIFICATIONS AND AIDS

Abbas Aminmansour, Ph.D.
Associate Professor and Chair
Structures Program, School of Architecture
University of Illinois at Urbana-Champaign, 61820 USA
117 Temple Buell Hall, MC-621
AAmin@uiuc.edu

ABSTRACT: The 2005 versions of the American Institute of Steel Construction (AISC) Specification and *AISC Manual* reflect the latest research results, new design aids and a new format combining information for Allowable Strength Design (ASD) and the Load and Resistance Factor Design (LRFD) methods. The ASD version of the AISC Specification and *AISC Manual* will no longer be published. This is a long anticipated significant move.

A major difference in approach between ASD and LRFD is in the way they incorporate factor of safety in design. ASD directly combines loads and incorporates structural safety by means of applying a factor safety (Ω) to the nominal strength while LRFD uses load factors (γ's) to magnify loads and resistance factors (Φ's) to reduce available strength. Both methods use specified load combinations to calculate the required strength. The 2005 AISC Specification combines these two approaches in a unified document. Much of the new AISC Specification is very similar to that of the previous LRFD Specification except for changes in certain areas.

The 13th edition of the *AISC Manual* includes introduction of new approaches to design of certain types of structural steel components such as members subjected to combined loads including compression plus bending and tension plus bending. The new methods and aids save time in design, allow for selection of more efficient sections, and facilitate choosing from a wide range of available steel sections. The tables also offer aids for design of beams, columns, and tension members. This presentation will begin with an overview of the new AISC Specification, *AISC Manual* and will continue with the above discussion, including example problems.

Keywords: steel; design; specifications; ASD; LRFD

1. INTRODUCTION

American steel design specifications, like their counterparts around the world, have gone through many evolutions since their inception in 1923. Often updates include state-of-the-art knowledge and new information learned from latest research and engineering practice. However, from time to time, considerable alterations are made in design standards that may include significant changes in procedures and even new design philosophies.

The American Institute of Steel Construction (AISC), the professional and trade organization that develops and publishes the design specifications for structural steel design in the United States published its latest version of its design standards called the 2005 AISC *Specification for Structural Steel Buildings*, hereafter referred to as the 2005 AISC Specification. The new standards reflect the stated mission of the Committee on Specifications which is: *Develop the practice-oriented specification for structural steel buildings that provides for*

- *life safety*
- *economical building systems*
- *predictable behavior and response*
- *effective use*

Later in 2005, the 13th edition of the AISC *Steel Construction Manual* was published as well. These publications incorporate some of the most significant changes throughout their history.

2. CHANGES IN THE NEW AISC SPECIFICATION

The new AISC Specification incorporates the following major changes.

2.1 INTEGRATION OF SEVERAL EXISTING SPECIFICATIONS

The 2005 AISC Specification integrates five previously existing AISC Specifications into one document, offering one comprehensive source including all design standards. The incorporated documents are:

a. The 1989 Specification for Structural Steel Buildings: Allowable Stress Design and Plastic Design
b. The 1989 Specification for Allowable Stress Design of Single Angles
c. The 1989 Load and Resistance Factor Design (LRFD) for Structural Steel Buildings
d. The Load and Resistance factor Design Specification for Steel Hollow Structural Sections (HSS)
e. The 2000 Load and Resistance factor Design Specification for Single Angle Members

2.2 UNIFIED SPECIFICATION

Since the adoption of the LRFD Specification in 1986, AISC published separate design standards and manuals; one for the previously existing ASD and one for the new LRFD. Later, AISC Board of Directors decided to place the ASD Specification and AISC-*ASD Manual of Steel Construction* on "maintenance hold". This meant that there would be no changes or updates to the ASD documents, except for correction of errors found. Consequently, the ASD documents did not benefit from new knowledge for several years and fell significantly behind. It is believed that at the time, AISC would have liked to do away with the ASD Specification and *ASD Manual* over a period of a few years. However, pressure from the practitioners, majority of whom knew ASD only, led to the Board deciding to put those documents on "maintenance hold" rather than phasing out of them over a period. In view of some, AISC should have made the decision to not continue with ASD years ago.

The existence of two sets of design specifications and two manuals was not the optimum circumstance for AISC to be in. For one thing, clearly publication and distribution of two sets of documents was not economical. But, perhaps more importantly, the mere existence of the two specifications raised the question; how could two different design methods based on different design philosophies be equally valid and appropriate?

The 2005 version of the AISC Specification offers an integrated approach for design of structural steel using either the Load and Resistance Factor Design (LRFD) or Allowable <u>Strength</u> Design (ASD) method. The ASD method offered in the new AISC Specification is a variation of what used to be known as the Allowable <u>Stress</u> Design (also referred to as ASD) method for many years. The new ASD is a strength based design method rather than its predecessor which was a stress based design method. This subject will be discussed later in this paper.

In summary, the 2005 AISC Specification combines ASD and LRFD methodologies while incorporating the latest developments in structural steel design. The 2005 AISC Specification is available for free download at http://www.aisc.org/2005spec.

2.2.1 STRUCTURAL SAFETY

The principal difference between the previous ASD (stress-based) and LRFD methods is in the way they incorporated structural safety. Therefore, before we proceed to a discussion on the new unified AISC Specification, a review of principles of structural safety is helpful.

The stress-based ASD method utilized structural safety through a factor of safety (Ω) applied to pertinent stress limits to obtain Allowable Stresses and thereby the name Allowable Stress Design (ASD) method. Safety factors used in ASD were based on a combination of theory, experiments and experience. LRFD, on the other hand, utilizes structural safety by using Load Factors (γ) and Resistance Factors (Φ), and therefore the name Load and Resistance Factor Design method. In either ASD or LRFD method, design has always been based on certain limiting conditions such as tension yielding, flexural buckling and lateral torsional buckling. However, due to differences between the two specifications, design of structural components (e.g. members, connections, etc.) required calculations which were significantly different between the two methods.

As noted earlier, the ASD method presented in the 2005 version of the AISC Specification is a strength-based design method rather than its predecessor which was a stress-based design method. Both ASD and LRFD methods presented in the 2005 AISC Specification expect that the Required Strength of structural components be equal to or less than the Available Strength as follows.

$$\boxed{\text{Required Strength} \leq \text{Available Strength}} \qquad \text{(Eq.-1)}$$

Inherently, there are uncertainties in the two parts that make up Equation 1. Therefore, it is necessary to consider factors of safety in design to account for variations or uncertainties in values of each part of this equation.

Available Strength of a structural component is dependent on its nominal strength. Nominal strength of a structural component is a *measure* of its real strength based on assumed material and cross sectional properties and includes a certain amount of unavoidable deviations from the actual value. Therefore, it is necessary to adjust this value in determining the Available Strength to account for structural safety. Further, the designer needs to consider the type and consequences of failure in determining the Available Strength of a structural component. Although no failures are desired, the fact is that they are different in the way they occur and the consequences of their occurrence. For example, while tension yielding of a member is a ductile failure and gives advance warning (through significant deformation) of the impending failure, tension rupture occurs in a very brittle (abrupt) way and without any prior warning. Further, we need to note that while some failures may cause local impacts, others may lead to more catastrophic failure by leading failures of other structural components.

Available Strength in LRFD is specifically called the Design Strength while it is called the Allowable Strength in ASD. Both LRFD's Design Strength and ASD's Allowable Strength depend on the same Nominal Strength (R_n) of the structural component. R_n is calculated based on the recognized applicable limit states.

The Required Strength, on the other hand, is determined based on structural analysis and the appropriate load combinations specific to each method. It depends on the applied loads and the structural analysis carried out to determine load effects such as axial loads, bending moments, shear forces and the like. There is always some level of uncertainty in the magnitude of the applied loads. Also, we need to account for the probability that more than one extreme load may occur simultaneously. In addition, we need to consider known errors occurred due to our analysis models and methods. For example, we often assume that "pin-ended" columns are axially loaded only and that they need not resist any bending moments. While this is a reasonable assumption and makes the analysis process simpler, in reality, there is always some bending moment in "pin-ended" columns due to factors such as eccentric connections or member crookedness. Therefore, the nominal load values obtained from the applicable building code and used in calculations need to be adjusted to account for uncertainty in their values while determining the Required Strength. Load factors and load combinations will be discussed in more details in the following section.

2.2.2 DEVELOPMENT OF THE BASIC LRFD EQUATION

Equation 1 given earlier represents in general the necessary relationship between the Required Strength and Available Strength of a structural component. One side of the inequality in Equation 1 has to do with the applied loads and the other with the strength of the structural component. Recall that LRFD integrates structural safety by magnifying the nominal loads using Load Factors (γ_i) and using load combinations on one hand and by reducing the Nominal Strength (R_n) of the member using the Resistance Factor (Φ), on the other.

In magnifying nominal loads, LRFD recognizes the variations or uncertainties in the magnitude of the applied loads as well as the combinations of different loads that may be present at a given time through probability based criteria. For instance, live load, by definition, may or may not be present at a particular time or may vary in magnitude. Dead load magnitudes, on the other hand, are calculated based on relatively well known materials used in construction and exhibit less variations than live load. Therefore, it makes sense to use different Load Factors (γ_i) for live load and dead load while incorporating structural safety. Further, the probability of presence of different load combinations should be considered. For example, the case when only dead loads are present should be treated differently from when live load and wind loads are present as well. In summary, structural safety should include a certain level of factor of safety based on variations in magnitudes and combinations of applied loads. Therefore, Equation 1 then may be written for LRFD as follows.

$$\boxed{\gamma_1 Q_1 + \gamma_2 Q_2 + \gamma_3 Q_3 + \ldots + \gamma_n Q_n \le \Phi R_n} \quad \text{(Eq. 2)}$$

or,

$$\boxed{\sum_{i=1}^{n} \gamma_i Q_i \le \Phi R_n} \quad \text{(Eq. 3)}$$

where,

Q_i =	Nominal loads (e.g. nominal live load, dead load, wind load, etc.)
γ_i =	Load factors for different load types
Φ =	Resistance factor
R_n =	Nominal strength of the structural component

Values of load and resistance factors are presented later. It can be generally stated that the LRFD method applies structural safety on one hand by magnifying loads (use of load factors γ_i) and on the other hand by reducing available strength (use of resistance factor Φ).

The left hand side of Equation 3 earlier defined as the Required Strength, is the sum of the products of each load type (Q_i) and its load factor (γ_i). Load factors are adjustment multipliers that account for variations or uncertainties in loads and the probability of presence of a certain combination of different loads at the same time. It is noted that load factors used with each type of load are not always the same and depend on the "load combination" or the existence of other loads.

Load factors and load combinations may be dictated by the applicable building code. However, in the absence of such information, the 2005 AISC Specification refers to the latest edition of *Minimum Design Loads for Buildings and Other Structures,* also known as *SEI/ASCE-7*, published by the American Society of Civil Engineers (ASCE) for the appropriate factored load combinations. The current (2005) edition of *SEI/ASCE-7* specifies the following factored loads and load combinations for design based on the LRFD method.

1.	$1.4(D+F)$	(Eq. 4)
2.	$1.2(D+F+T) + 1.6(L+H) + 0.5(L_r \text{ or } S \text{ or } R)$	(Eq. 5)
3.	$1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.8W)$	(Eq. 6)
4.	$1.2D + 1.6W + L + 0.5(L_r \text{ or } S \text{ or } R)$	(Eq. 7)
5.	$1.2D + 1.0E + L + 0.2S$	(Eq. 8)
6.	$0.9D + 1.6W + 1.6H$	(Eq. 9)
7.	$0.9D + 1.0E + 1.6H$	(Eq. 10)

where D, E, F, H, etc. are nominal (unfactored) loads as identified below. Constant numbers in front of the loads (e.g. 1.4, 1.2, 1.6, 0.5, etc.) are the load factors (γ's) for the particular load combination under consideration.

D = dead load
E = earthquake load
F = load due to fluids with well-defined pressures and maximum heights
H = load due to lateral earth pressure, ground water pressure, or pressure of bulk materials
L = live load
L_r = roof live load
R = rain load
S = snow load
T = self-straining force
W = wind load

Each load is either calculated or otherwise obtained from the applicable building code. Theoretically, all possible load combinations should be calculated. The factored load used in Equation 3 is the largest value obtained. The reader is referred to *SEI/ASCE-7* for more information on load types, load calculations, load combinations, exceptions and other pertinent information.

The AISC Specification simply refers to the *SEI/ASCE-7* for all load combination calculations. This is a rational approach because the bases for establishing load factors and load combinations are independent of the construction material (e.g. steel, concrete, etc.). Further, with this approach, future changes in load factors and load combinations do not require changes in the AISC Specification.

As discussed earlier, the Available Strength in LRFD, also called the Design Strength, is the product of Nominal Strength (R_n) and the appropriate Resistance Factor (Φ) to account for structural safety. The Resistance Factor (Φ) is a number less than one and therefore adjusting the Nominal Strength to a smaller value for structural safety. Values of the Resistance Factor

(Φ) for design for different load effects are given in the appropriate chapters of the AISC Specification. Following are example values for the Resistance Factor.

Φ = 0.90 for limit states involving yielding (such as tension or flexural yielding)
Φ = 0.75 for limit states involving rupture (such as tension or shear rupturing)

2.2.3 DEVELOPMENT OF THE BASIC ASD EQUATION

Equation 1 given earlier represents in general the necessary relationship between the Required Strength and Available Strength of a structural component regardless of the method of design. Recall that the left side of the inequality this equation has to do with the applied loads and the right side with the strength of the structural component. The ASD method introduced in the 2005 version of the AISC Specification integrates structural safety by reducing the nominal strength of the member using a single Factor of Safety (Ω).

Except in a few special load combinations, the Allowable Strength Design method does not distinguish between load types and treats them all the same regardless of the possible variations or uncertainties in load magnitudes. ASD does, however, require consideration of different load combinations. Therefore, Equation 1 then may be written for ASD as follows.

$$\boxed{\sum_{i=1}^{n} \gamma_i Q_i \le \left(\frac{R_n}{\Omega}\right)} \qquad \text{(Eq. 11)}$$

where,

Q_i = Nominal loads (e.g. nominal live load, dead load, wind load, etc.)
γ_i = Load factors for different load types
Ω = Factor of safety
R_n = Nominal strength of the structural component

Equation 11 represents the basic formula used in the ASD method. The current (2005) edition of SEI/ASCE-7 specifies the following load combinations for design based on the ASD method.

1.	$D+F$	(Eq. 12)
2.	$D+H+F+L+T$	(Eq. 13)
3.	$D+H+F+(L_r \text{ or } S \text{ or } R)$	(Eq. 14)
4.	$D+H+F+0.75(L+T)+0.75(L_r \text{ or } S \text{ or } R)$	(Eq. 15)
5.	$D+H+F+(W \text{ or } 0.7E)$	(Eq. 16)
6.	$D+H+F+0.75(W \text{ or } 0.7E)+0.75L+0.75(L_r \text{ or } S \text{ or } R)$	(Eq. 17)
7.	$0.6D+W+H$	(Eq. 18)
8.	$0.6D+0.7E+H$	(Eq. 19)

where *D*, *E, F, H*, etc. are nominal (unfactored) loads as identified earlier under LRFD load combinations. See *SEI/ASCE-7* for more information on load types, load calculations, load combinations, exceptions and other pertinent information.

The Available Strength in ASD is the division of Nominal Strength (R_n) and the appropriate Factor of Safety (Ω) to account for structural safety. The Factor of Safety (Ω) is a number larger than one and therefore adjusting the Nominal Strength to a smaller value for structural safety as explained earlier. Values of the Resistance Factor (Ω) are given in the appropriate chapters for each Nominal Strength. Following are a number of examples of the Resistance Factor.

Ω = 1.67 for limit states involving yielding (such as tension or flexural yielding)
Ω = 2.00 for limit states involving rupture (such as tension or shear rupturing)

2.2.4 UNIFIED APPROACH

As observed above, the 2005 version of the AISC Specification unifies the procedures for design of structural steel, regardless of the method used. Generally speaking, the designer calculates the nominal strength (R_n) which is the same regardless of the method used. Then (s)he applies either γ_I's and Φ for LRFD or Ω for ASD. In either case, the appropriate load combinations given by ASCE-7 are used. This process is not only simpler than before, but it incorporates the state-of-the-art knowledge in the specifications applying to both ASD and LRFD.

The organization of the 2005 Specification is very similar to both the 1989 ASD Specification and the 1999 LRFD Specification. However, significant changes have occurred in the content of the Appendices. The new Specification is also fully coordinated with the *2005 AISC Seismic Provisions* and the *2005 AISC Code of Standard Practice*. A document called *Cross-Reference List for the 2005 AISC Specification to Past AISC Specifications* is available for those transitioning between 2005 and previous AISC specifications. This document is available for free download from the AISC web site (http://www.aisc.org).

2.3 INCORPORATION OF SINGLE ANGLE AND HSS DESIGN SPECIFICATIONS

As noted in Section 2.1 above, in the past, AISC offered separate specifications for design of single angles and Hollow Structural Sections. The 2005 AISC Specification includes provisions for design of single angle and hollow structural sections member incorporated as part of the new specification and within the appropriate Chapters. For example, design of single angle or HSS compression members is now part of Chapter E, Design of Members for Compression, rather than being contained in a separate document.

2.4 CHANGES TO INDIVIDUAL CHAPTERS

Individual Chapters of the AISC Specification have been updated to include the latest information for both ASD and LRFD methods. Further, chapter scopes have changed to include broader flexibility, coverage and uniform procedures for design of structural components. Chapter A presents an expanded scope that allows application of the entire document for not only "design of structural steel buildings," but to "other structures" as well. Other structures are defined as "those structures designed, fabricated, and erected in a manner similar to buildings, with building-like vertical and lateral load-resisting elements."

There are changes in other Chapters of the AISC Specification as well. For example, Chapter F, Design of Members for Flexure, provides standards for design of all section types for bending, including HSS and single angles. Single angle and hollow structural section (HSS) criteria are incorporated in the pertinent design chapters. New chapters, such as Chapter G, Design of Members for Shear and Chapter K Design of HSS and Box Member Connections are added to the Specification.

2.5 INTRODUCTION OF USER NOTES

The 2005 AISC Specification offers the usual Commentary and Appendix sections for more detailed information and background on the specifications presented in each Chapter. However, in addition, User Notes are inserted in the new Specification to highlight or draw attention to certain points. User Notes appear in a distinct shaded boxes throughout the Specifications.

3. CHANGES IN THE NEW AISC MANUAL

The 2005 *AISC Steel Construction Manual* is called the Thirteenth edition, indicating that it is the new version after nine editions of ASD and three LRFD *Manuals*. It incorporates the latest AISC Specification as well as new design aids. The new *Manual* was formatted for simpler use. One major change in the new manual is a significant expansion of design examples, which have been removed from the printed version and included on a CD which accompanies the printed volume.

The new *AISC Manual* includes one set of design aids (e.g. tables, charts, etc.) for use with both ASD and LRFD methods. Typically, Available Strength for use with the ASD method (R_n/Ω) are given in areas with green background, while LRFD values are given in blue text and white background.

Some Parts of the new *AISC Manual* have been moved around. For example, Part Three which used to be on Design of Tension Members has switched place with Part Five which is Design of Flexural Members. Sample examples of design aids in the new *AISC Manual* will be presented at the conference.

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